

# Searching for near-infrared counterparts of the faint neutron star X-ray transients XMMU J174716.1–281048 and SAX J1806.5–2215

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## ABSTRACT

We present our near-infrared (NIR) imaging observations of the two neutron star low mass X-ray binaries XMMU J174716.1–281048 and SAX J1806.5–2215 obtained using the PANIC instrument on the 6.5-meter Magellan telescope and the WHIRC instrument on 3.5-meter WIYN telescope. Both sources are members of the group of faint to very-faint X-ray binaries and are undergoing very long X-ray outbursts since 2003 and 2011, respectively- ‘the quasi-persistent X-ray binaries’. The goal of our observations is to identify the NIR counterpart of both sources. We identified two NIR stars consistent with the Chandra X-ray error circle of XMMU J174716.1–281048 and one for SAX J1806.5–2215. We studied the magnitude variations of the possible counterparts with respect to the UKIRT NIR Galactic plane observations. For XMMU J174716.1–281048, we also investigated the candidate counterparts using the color-color diagram and spectral energy distribution. We observed large variability in one NIR star having position consistent with the Chandra error circle of XMMU J174716.1–281048, the observed NIR band magnitudes of which suggest a low-mass star. From the available data it is inconclusive whether or not this source is the counterpart of XMMU J174716.1–281048. Future NIR spectroscopic observations will help us in determining whether or not this NIR source is related to the X-ray source. For SAX J1806.5–2215, we have very likely identified the real NIR counterpart.

**Key words:** stars: binaries – general, X-ray: binaries – stars: neutron – accretion, accretion disks – individual: XMMU J174716.1–281048, SAX J1806.5–2215

## 1 INTRODUCTION

Low-mass X-ray binaries (LMXBs) are binary systems with a compact star (neutron star or black-hole) accreting matter from a low-mass star (usually K, M dwarf or red giant) while they revolve around each other. Occasionally most of these systems undergo a large increase in X-ray luminosities (by a factor more than 1000) displaying peak X-ray luminosities of  $10^{37-39}$  erg s<sup>−1</sup>. These X-ray outbursts last for a few weeks to months except in some of the LMXBs in which they last up to a few years or rarely a decade as well. The sources with these long X-ray outbursts (> 1 year) are also known as quasi-persistent LMXBs. During these outbursts,

the majority of the X-rays are emitted in the inner accretion disk while the optical/infrared (OIR) light is emitted due to the reprocessed emission in the outer accretion disk and the surface of the companion star. In the quiescence state, the OIR light dominantly comes from the low-mass companion star and allows us to identify the companion star which is important to constrain the mass of the compact object.

During the last decade, many faint to very-faint X-ray transients have been discovered with peak X-ray luminosities of  $10^{34-36}$  erg s<sup>−1</sup> (Wijnands et al. 2006, Degenaar and Wijnands 2010). Most of these sources are discovered in the Galactic plane and a large fraction of them were discovered through the thermonuclear bursts (Cornelisse et al. 2002b). These bursts have so far been observed only from the neutron star LMXBs hence probably these faint transients are

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also members of LMXBs. However the current instability models that explain the transient behaviour of LMXBs (e.g., Lasota 2001) cannot explain the low peak X-ray luminosities of these faint systems. It is possible that these sources are accreting from the stellar wind of a companion star (Pfahl et al. 2002) or they have a small accretion disk, which indicate a small orbit that can only accommodate a very small donor star - e.g., brown dwarfs or white dwarfs - the latter are called ultra-compact X-ray binaries with extremely short orbital periods ( $< 80$  minutes; Nelemans and Jonker 2010). To confirm these proposed scenarios, there have been efforts to identify the OIR counterpart of them (Kaur et al. 2011a, Kaur et al. 2011b, Degenaar et al. 2010, Kaur et al. 2010, Kaur et al. 2009), however most of the times, high extinction and crowded OIR fields in the Galactic plane hamper the detection and identification of the real counterpart. In this paper we present our near-infrared (NIR) imaging observations of two faint to very faint quasi-persistent transients to search for their counterpart.

### 1.1 XMMU J174716.1–281048

XMMU J174716.1–281048 (hereafter XMM1747) was serendipitously discovered during a pointed *XMM-Newton* observation of the supernova remnant G0.9+0.1 performed on March 12, 2003. The source had an X-ray flux of  $3.7 \times 10^{-12}$  erg cm $^{-2}$  s $^{-1}$  in 2–10 keV energy band (Sidoli and Mereghetti 2003, Sidoli et al. 2004, Del Santo et al. 2007b). The source X-ray spectrum was best fitted with an absorbed powerlaw model with index  $\Gamma$  of 2.1 and a hydrogen column density  $N_H$  of  $8.9 \times 10^{22}$  cm $^{-2}$ . Being located near the Galactic center, the source distance was estimated to be  $\sim 8$  kpc, hence the X-ray luminosity of the source was  $\sim 3 \times 10^{34}$  erg s $^{-1}$ . The source was not visible in the previous *XMM-Newton* and *Chandra* observations performed between September 2000 and July 2001 which implied that the quiescent X-ray luminosity of the source was  $\leq 10^{32}$  erg s $^{-1}$  (Del Santo et al. 2007b). The rise in flux by a factor more than 100 and with low peak X-ray luminosity classifies the source as a very faint X-ray transient (Wijnands et al. 2006).

On March 22, 2005, the *INTEGRAL*/JEM-X detected a transient IGR J17464–2811 because it exhibited a type-I X-ray burst (Brandt et al. 2006). The position coincidence of this burst source with the position of XMM1747, which was also active during observations made on Feb 25–26, 2005 using the *XMM-Newton* satellite (Sidoli et al. 2006) indicated that both sources are the same source (Wijnands 2006). This classifies XMM1747 as a neutron star low mass X-ray binary. On the basis of the properties of the X-ray burst observed by the *INTEGRAL* satellite, it was suggested that the source was likely continuously active between 2003 and 2005 and was undergoing a long-term outburst (Del Santo et al. 2007b). Since 2007, XMM1747 has been observed once using the *Chandra* satellite and several times using the *Swift* satellite and is detected at similar fluxes in all observations and with very similar X-ray spectral parameters (Degenaar and Wijnands 2007, Degenaar et al. 2007, Campana 2009, Sidoli et al. 2007, Del Santo et al. 2007a, 2007b, 2009, 2010, 2011, 2012). This suggests that the source has been in outburst for at least 8 years and hence that it belongs to the quasi-persistent X-ray transients. Another type-I X-ray burst was

observed from this source on August 13, 2010 (Degenaar et al. 2011b) using the *Swift*/Burst Alert Telescope (BAT).

The best known position of the source so far is RA :  $17^h 47^m 16^s.16$ , Dec. :  $-28^\circ 10' 48''.0$  with an error circle of  $0''.5$  (Degenaar et al. 2007). A possible NIR counterpart of XMM1747 was reported at this position from the observations obtained on May 27, 2007 using instrument ANDICAM on the 1.3-meter SMARTS telescope. The source had a *H* band magnitude of  $15.3 \pm 0.1$  mag but was not detected in the *V* and *I* band (Degenaar et al. 2007).

### 1.2 SAX J1806.5–2215

SAX J1806.5–2215 (hereafter SAX1806) was discovered using the *BeppoSAX*/Wide Field Cameras (WFC) through the detection of two type-I X-ray bursts observed between August 1996 to October 1997 (In't Zand et al. 1999, Cornelisse et al. 2002a). At the time when these X-ray bursts occurred, no persistent X-ray emission was detected from the source. However, it was later found using the *RXTE*/All Sky Monitor data of the source that it was faintly active for nearly two years at this time (from early 1996 till late 1997) with the peak persistent flux of  $\simeq 2 \times 10^{-10}$  erg cm $^{-2}$  s $^{-1}$  (2–10 keV; Cornelisse et al. 2002a). Using the unabsorbed bolometric peak flux of the brightest burst, an upper limit of 8 kpc on source distance was obtained (Cornelisse et al. 2002a). Using this distance, outburst accretion X-ray luminosity of the source was  $\simeq 2 \times 10^{36}$  erg s $^{-1}$ .

On February 22, 2011, after 12 years in quiescence SAX1806 displayed another X-ray outburst (Altamirano et al. 2011) and at the time of writing of the paper, the source is still active ( $> 1$  year after the start of the outburst; Kaur et al. 2012b). *Swift*/XRT observations obtained on March 1, 2011 detected one bright source, within the *BeppoSAX* error circle of the source. The X-ray spectrum could be well fitted with a powerlaw model of  $\Gamma \sim 2$  and  $N_H$  of  $\sim 5.6 \times 10^{22}$  cm $^{-2}$  (Degenaar et al. 2011a). The unabsorbed flux of the source suggest an X-ray luminosity of  $\sim 2 \times 10^{36}$  erg s $^{-1}$  (for a distance of 8.0 kpc; Degenaar et al. 2011b) which is similar to the X-ray activity level seen during its previous outburst. A *Chandra* observation of the source provided the best known position of the source with a  $0''.6$  accuracy (90% confidence level) at RA :  $18^h 06^m 32^s.177$  and Dec :  $-22^\circ 14' 17''.20$  (Chakrabarty et al. 2011). Previous *Chandra* and *Swift* observations of the source obtained between 2000–2009 did not detect the source with an upper limit on the X-ray luminosity of  $(0.5 - 2) \times 10^{33}$  erg s $^{-1}$  (Chakrabarty et al. 2011, Degenaar et al. 2011a, Campana 2009). The low peak X-ray luminosity of the source and the long outburst classify SAX1806 as a faint quasi-persistent X-ray transient.

During the X-ray outburst, a NIR counterpart was detected in our  $K_s$  band observations obtained in March 2011 using the WHIRC instrument on the 3.5-meter WIYN telescope (Kaur et al. 2011b) and the observations will be discussed in detail in this paper.

## 2 DATA REDUCTION AND ANALYSIS

XMM1747 was observed on May 25, 2008 in the *J*, *H* and  $K_s$  wavebands using the PANIC instrument mounted on the

6.5-meter Baade Magellan telescope at Las Campanas Observatory in Chile; PANIC has a  $1024 \times 1024$  array of pixels with  $0''.125/\text{pixel}$  sampling, corresponding to  $2' \times 2'$  field of view. All the science exposures were taken as a set of 5 dithers and a loop of three 10s exposures were performed at each of the 5 dither points (dice 5 pattern). The source was observed for a total exposure time of 300s, 300s and 750s in the  $J$ ,  $H$  and  $K_s$  filters, respectively.

SAX1806 was observed in the  $K_s$  band on March 23, 2011 using the WIYN High-Resolution Infrared Camera (WHIRC, Meixner et al. 2010) mounted on the 3.5-meter WIYN telescope located at Kitt Peak National Observatory in USA. WHIRC has a  $2048 \times 2048$  array with  $0''.1$  arc-sec/pixel sampling, resulting in a field-of-view of  $3.3' \times 3.3'$ . The source was observed for a total exposure time of 720s, which include 40s exposure at each of the  $3 \times 3$  dither pattern, repeated twice.

Data reduction for XMM1747 is performed using the PANIC data reduction package version 0.95<sup>1</sup>. For SAX1806, we used a custom-made reduction pipeline that largely follows the recipe outlined in the WHIRC Data Reduction Guide<sup>2</sup>. In short, for both the sources, after removing the inherent detector nonlinearity we performed a background subtraction, flat-fielding, geometric distortion correction, alignment and finally stacking of science images. The seeing in the stacked XMM1747 images is  $0''.5$  and SAX1806  $K_s$  image is  $0''.6$ .

We used both twilight sky flats and dome flats for the XMM1747 while only dome flats were used for SAX1806. The dome flats are preferred for WIYN observations due to the open structure of the telescope and its susceptibility to stray light from the relatively bright sky. Dome flat-fields were taken with the flat-field lamps switched on and off to account for thermal emission from the warm dome. Sky-background levels of science images were estimated by iterative sigma-clipping of the brightness distribution of each of the data-frames. Multiple frames at different dither positions were then normalised by their respective sky-levels, median-combined to remove stars, and then scaled to the sky-level of each data frame and subtracted.

We determined the astrometry for both the sources using the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) stars and fitting them for the transformation using *ccmap*. The solution for the  $J$  image of XMM1747 had an rms error of  $0''.03$  in each coordinate and we transferred this solution to the  $H$  and  $K_s$  wavebands also. For SAX1806, the  $K_s$  image had a rms error of  $0''.03$  and  $0''.05$  in X and Y coordinate respectively.

We ran *Sextractor* (Bertin and Arnouts 1996) on our observations to measure the instrumental magnitude of stars. To calibrate the observations, we used the archival 3.5-meter United Kingdom Infra-red Telescope (UKIRT) observations of the source field in  $J$ ,  $H$  and  $K$  bands which were obtained as a part of the UKIDSS Galactic plane survey (Lucas et al. 2008). These observations were taken on July 18, 2006 for XMM1747 and July 23, 2006 for SAX1806 using the wide field infrared camera (WFCAM) composed of four Rockwell Hawaii-II  $2048 \times 2048$  18 micron pixel array detectors, with

a pixel scale of  $0''.4$ . We determined zero point for our observations using 25 or more well-isolated and well-detected stars and obtained the zero point uncertainties of 0.02 mag for both sources XMM1747 and SAX1806. Because we calibrated our  $K_s$  band observations with respect to the UKIRT  $K$  band observations, the magnitudes are discussed in  $K$  band in the further discussions. The observed magnitude of both sources from our observations are listed in Table 1.

We also utilise data from the *Spitzer* Space Telescope's (Werner et al. 2004) Galactic Legacy Infrared Mid-Plane survey Extraordinaire (GLIMPSE; Benjamin et al. 2003) for our sources.

### 3 RESULTS

#### 3.1 XMMU J174716.1–281048

Our Magellan observations of the source in  $J$ ,  $H$  and  $K_s$  bands were taken during the ongoing X-ray outburst which started in 2003. Figure 1 shows the Magellan  $K_s$  band image of XMM1747 where the *Chandra* X-ray position of the source is marked with its error circle. No other X-ray star was detected in the *Chandra* image, therefore we could not further refine the position of the source through astrometry. We detect two NIR stars consistent with the *Chandra* error circle of the source at positions RA, Dec =  $17^h 47^m 16^s.20$ ,  $-28^\circ 10' 47''.62$  and  $17^h 47^m 16^s.16$ ,  $-28^\circ 10' 48''.72$  with a positional uncertainty of  $0''.03$  and are marked as C1, C2 in Figure 1. The observed magnitude of both stars are listed in Table 1.

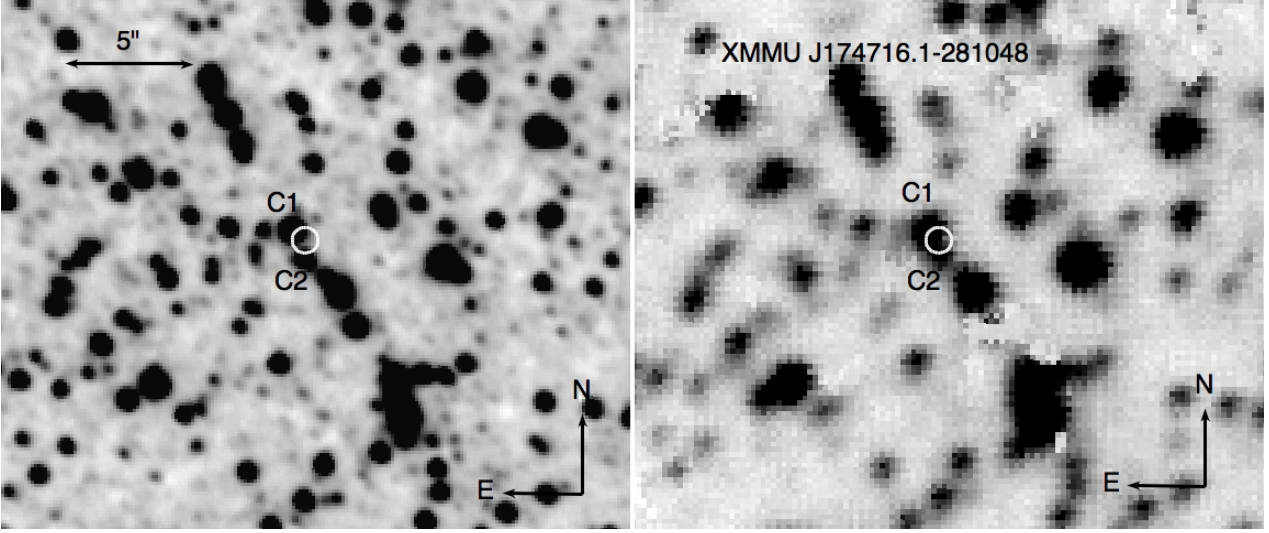
The source was also observed on July 18, 2006 in  $J$ ,  $H$  and  $K$  bands during the UKIDSS Galactic plane survey (Lucas et al. 2008). Both stars C1 and C2 are visible during these observations as well, but only the magnitude of star C1 is listed in the WFCAM science archive<sup>3</sup> of the UKIDSS surveys, likely because both stars are blended partially in these observations and also star C2 is faintly detected. For a comparison, we also show the  $K$  band image of the source from these observations in Figure 1. To measure the observed magnitude of fainter star C2, we did photometry of these observations and calibrated with respect to the other stars whose magnitude was measured in the catalog. The magnitudes thus obtained in  $J$  and  $H$  and  $K$  bands are listed in Table 1.

Both the Magellan and UKIRT observations of the source were taken during the ongoing X-ray outburst of the source in 2008 and 2006 respectively. During the two epochs, the magnitudes of star C1 are consistent with each other within the errors while the fainter star C2 varied by almost 2 magnitudes in the  $K$  band (see Table 1). The source was also observed using ANDICAM instrument on the SMARTS telescope with  $H$  band magnitude of  $15.3 \pm 0.1$  mag in 2007 (Degenaar et al. 2007) which is consistent with the  $H$  band magnitude of the brighter star C1, shows that the flux during these observations were dominated by that of C1.

We also looked at the color-color and color-magnitude diagrams of the field using the UKIDSS Galactic plane observations, shown in Figure 2. The two flux measurements

<sup>1</sup> <http://code.obs.carnegiescience.edu/panic>

<sup>2</sup> [http://www.noao.edu/kpno/manuals/whirc/WHIRC.Datared\\_090824.pdf](http://www.noao.edu/kpno/manuals/whirc/WHIRC.Datared_090824.pdf) <http://surveys.roe.ac.uk/wsa/>



**Figure 1.** Left : Magellan  $K_s$  band image of XMM1747. Right : UKIRT  $K$  band image of XMM1747. In both images the white circle represents the Chandra X-ray position, with an error radius of  $0''.5$ . The two candidate near-infrared counterparts are marked as C1 and C2.

of both candidate counterparts are also marked. Both candidate counterparts seem to be a part of the field population, however the star C2 is likely suffering a bit more reddening than most of the population.

The spectral energy distribution (SED) of both candidate counterparts are also investigated. Among the two candidates, only star C1 is listed in the GLIMPSE catalog as SSTGLMA G000.8344+00.0834 and is detected at  $3.6\mu\text{m}$  and  $4.5\mu\text{m}$  with  $12.20 \pm 0.09$  and  $12.02 \pm 0.11$  mag, respectively. The Magellan observations allowed us to measure the magnitudes of both candidate counterparts with better confidence than the UKIRT observations. Therefore, to investigate SED, we have used magnitudes from the Magellan observations. The observed SED of both stars C1 and C2 is shown in Figure 3. We estimated the extinction in the direction of the source in  $J$ ,  $H$  and  $K$  bands using the relation  $N_H/A_V = 2.21 \times 10^{21}$  (Güver and Özel 2009) and following Fitzpatrick (1999). The  $N_H$  of the source measured from the X-ray spectral fit is  $\sim 8$  times higher than the Galactic  $N_H$  as measured by Dickey and Lockman (1990) in the direction of the source using the Lyman- $\alpha$  and 21-cm line. It is therefore possible that some of the  $N_H$  could be local to the X-ray source. For completeness, we measured extinction in different bands using both  $N_H$  (henceforth  $A^s$  - extinction calculated using  $N_H$  from the X-ray spectral fit,  $A^g$  - extinction calculated using  $N_H$  as measured by Dickey and Lockman (1990) in the direction of source). The extinction corrected magnitude of both stars from the Magellan and *Spitzer* observations are listed in Table 2. Here we assumed that the NIR star is experiencing the same  $N_H$  as that of X-ray source. However, if it is different, then our results can change significantly.

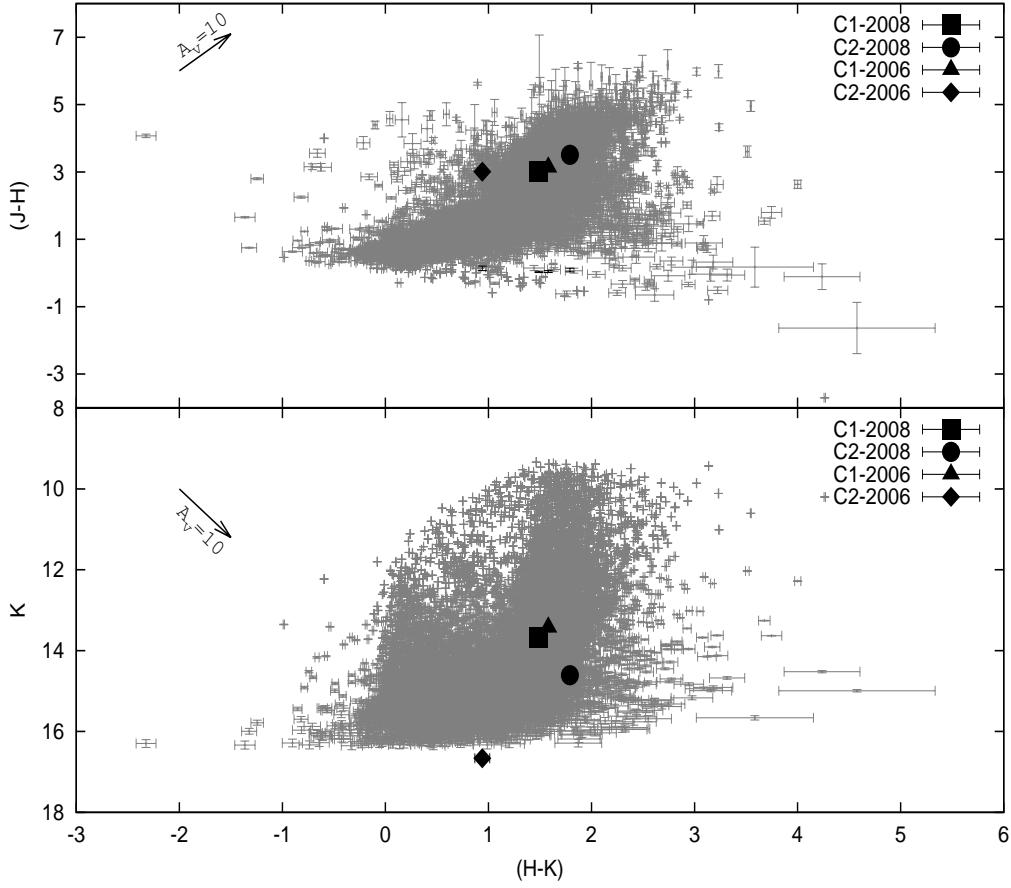
We fitted the de-reddened SED of candidate stars C1 and C2 with a single power-law model ( $\lambda F_\lambda = \lambda^\beta$ ). For the disk dominated LMXBs,  $\beta$  ranges from -2.5 to -1.5 (Hynes 2005, Kaur et al. 2012a). From our observations, only the de-reddened SED of star C1, corrected from  $A^s$  could be

fitted with a single power-law model of index  $\beta = -2.5 \pm 0.2$ .

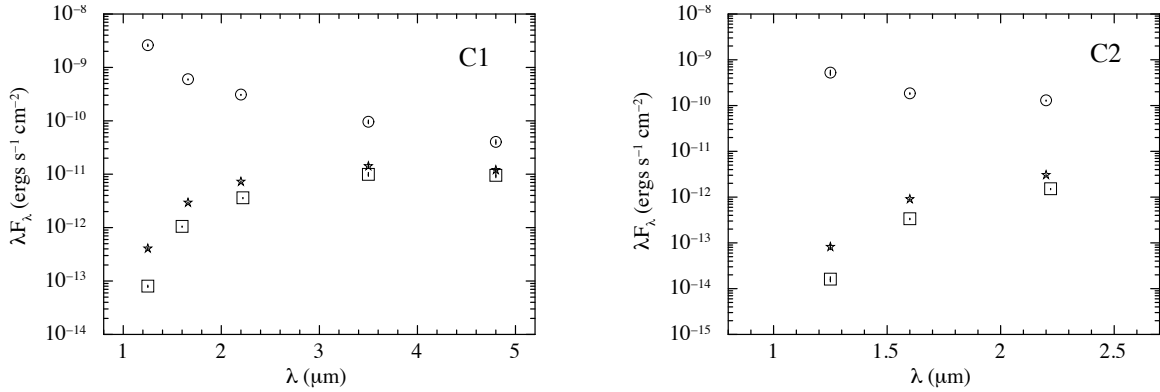
If the accretion disk is small in this source, then the companion star might dominate over the disk, in which case a black-body fit to the SED would indicate the spectral type of the companion star. However the small range of wavelength covered during our observations and the large uncertainties in the extinction does not allow to fit the observed fluxes for realistic parameters of a star. Assuming that all the NIR emission is from the companion star, we estimated the distance to different type of stars (main-sequence, giants and supergiants; Cox 2000) using the given de-reddened  $K$  band flux and a black-body model. The  $K$  band flux of star C1 corrected from  $A^s$  suggest a star earlier than O5 or a supergiant of B-type while the one corrected from  $A^g$  suggest an early B-type main-sequence star, respectively at a distance of 8 kpc. Similarly, the  $K$  band flux of star C2 from Magellan observations corrected from both  $A^s$  and  $A^g$  suggest that it could be a star of spectral type O and late B-type main-sequence star, respectively. However the star C2 was much fainter during the UKIRT observations and suggest an early B-type star or A-type star from the observed magnitudes corrected from  $A^s$  and  $A^g$ , respectively. We also estimated the extinction and distance to different stars (Cox 2000) using the observed colors of both candidate counterparts from their both Magellan and UKIRT observations and the results are consistent with the one using the black-body model.

### 3.2 SAX J1806.5–2215

We observed SAX1806 in the  $K_s$  waveband on March 23, 2011 during the ongoing X-ray outburst of the source, shown in Figure 4. The best measured *Chandra* X-ray position of the source is marked in the figure with the corresponding  $0''.6$  error circle. In our observations, we detected one NIR star at RA, Dec (J2000) =  $18^{\text{h}} 06^{\text{m}} 32^{\text{s}}.17$ ,  $-22^\circ 14' 17''.32$ , with an error circle of  $0''.03$  and  $0''.05$  in X and Y coordi-



**Figure 2.** Color-color and color-magnitude diagram of the source field of XMM1747 from the UKIDSS Galactic plane survey observations. The arrow represents the extinction,  $A_V=10$  mag. Both Magellan (2008) and UKIRT (2006) observations of candidate counterparts C1 and C2 are also marked.



**Figure 3.** The spectral energy distribution of candidate counterparts C1 and C2 of XMM1747. The squares represent the observed fluxes from the Magellan and *Spitzer* observations, circles represent the de-reddened fluxes corrected from the extinction calculated using the  $N_H$  obtained from the X-ray spectral fit and stars represent the de-reddened fluxes, corrected from the extinction calculated using the Galactic  $N_H$  as given by Dickey and Lockman (1990).

**Table 1.** Observed near-infrared magnitudes of XMM1747 and SAX1806 from the Magellan and WIYN observations respectively. The UKIRT and *Spitzer*/GLIMPSE magnitudes of the source are also listed.

Telescope (Date)	Source name	Filters				
		$J$	$H$	$K$	3.5 $\mu\text{m}$	4.8 $\mu\text{m}$
Magellan (May 25, 2008)	XMM1747 - C1	$18.17 \pm 0.05$	$15.16 \pm 0.01$	$13.67 \pm 0.01$		
	XMM1747 - C2	$19.91 \pm 0.14$	$16.40 \pm 0.03$	$14.61 \pm 0.01$		
UKIRT (July 18, 2006)	XMM1747 - C1	$18.14 \pm 0.07$	$15.01 \pm 0.01$	$13.43 \pm 0.01$		
	XMM1747 - C2	$20.61 \pm 0.20$	$17.60 \pm 0.04$	$16.66 \pm 0.06$		
<i>Sptizer</i>	XMM1747 - C1				$12.20 \pm 0.09$	$12.02 \pm 0.11$
WIYN (March 23, 2011)	SAX1806	-	-	$17.21 \pm 0.04$	-	-

**Table 2.** Extinction corrected magnitudes of XMM1747 and SAX1806 from the Magellan, WIYN and *Spitzer*/GLIMPSE observations. The extinction in different bands are calculated using the  $N_{\text{H}}$  from the X-ray spectral fit (represented by superscript ‘s’) and the Galactic  $N_{\text{H}}$  (represented by superscript ‘g’) as measured by Dickey and Lockman (1990).

Telescope	Object	$N_{\text{H}}$ ( $\times 10^{22} \text{ cm}^{-2}$ )	$J$ (mag)	$H$ (mag)	$K$ (mag)	3.5 $\mu\text{m}$ (mag)	4.8 $\mu\text{m}$ (mag)
Magellan	XMM1747 -C1	$8.9^{\text{s}}$	$6.89 \pm 0.05$	$8.31 \pm 0.01$	$8.83 \pm 0.01$	$9.74 \pm 0.09$	$10.45 \pm 0.11$
	XMM1747 -C1	$1.4^{\text{g}}$	$16.41 \pm 0.05$	$14.09 \pm 0.01$	$12.94 \pm 0.01$	$11.82 \pm 0.09$	$11.77 \pm 0.11$
	XMM1747 -C2	$8.9^{\text{s}}$	$8.63 \pm 0.14$	$9.55 \pm 0.03$	$9.77 \pm 0.01$	-	-
	XMM1747 -C2	$1.4^{\text{g}}$	$18.15 \pm 0.14$	$15.33 \pm 0.03$	$13.88 \pm 0.01$	-	-
<i>Spitzer</i>	XMM1747 - C1	$8.9^{\text{s}}$	-	-	-	$9.74 \pm 0.09$	$10.45 \pm 0.11$
	XMM1747 - C2	$1.4^{\text{g}}$	-	-	-	$11.82 \pm 0.09$	$11.77 \pm 0.11$
WIYN	SAX1806	$5.6^{\text{s}}$	-	-	$14.26 \pm 0.04$	-	-
	SAX1806	$1.2^{\text{g}}$	-	-	$16.55 \pm 0.04$	-	-

nates, consistent with the *Chandra* position of the source with a  $K$  magnitude of  $17.21 \pm 0.04$  mag. We note that this magnitude differs by 0.2 mag as compared to the previous reporting of our observations (Kaur et al. 2011b) and we believe this could be related to the calibration of the observations which was done with respect to the 2MASS during the previous analysis and UKIRT observations in this paper. Also it could be due to the zero-point calculations which are better constrained from the UKIRT observations.

The source field was also observed during quiescence on July 23, 2006 in the NIR  $K$  band using the UKIRT telescope as a part of the UKIDSS Galactic plane survey but was not detected during these observations. The self calibration of UKIRT  $K$  band image gave a limiting magnitude of 18.2 mag. This implies that during outburst the source got brighter by at least 1 magnitude.

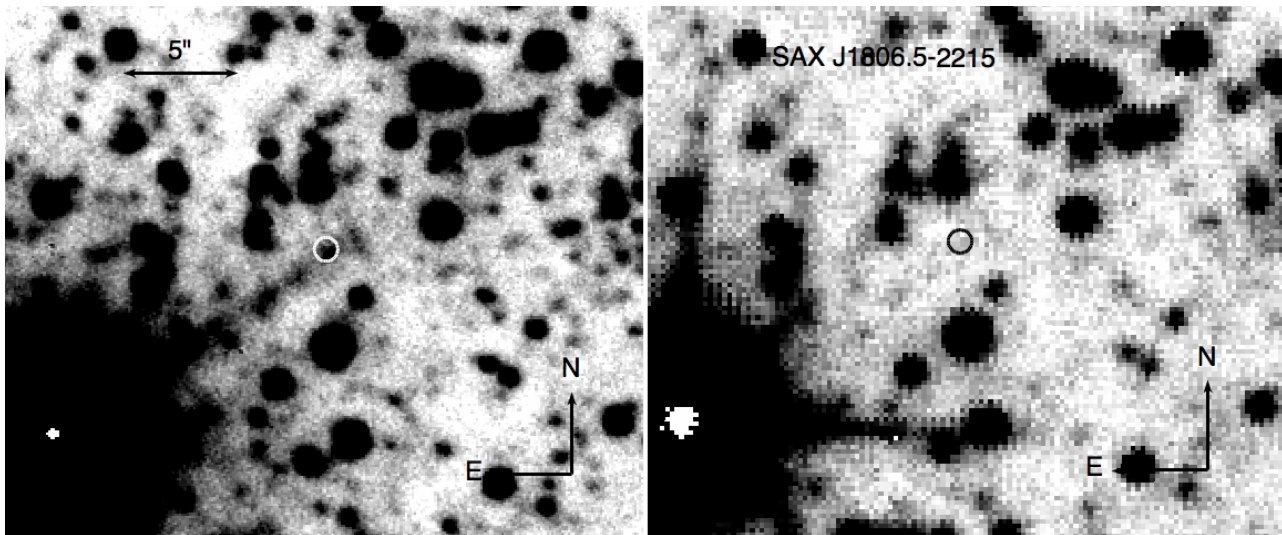
The  $N_{\text{H}}$  of the source from the X-ray spectral fit is 4 times larger than the Galactic  $N_{\text{H}}$  measured in the direction of the source. Similar to XMM1747, the extinction is measured using both  $N_{\text{H}}$  and the extinction corrected magnitudes thus obtained are listed in Table 2. Assuming that the quiescence magnitude of the source is 18.2 mag or fainter in  $K$  band, we estimate a companion star to be of spectral type F or later.

## 4 DISCUSSION

In this paper, we aimed to find the possible NIR counterparts of two ‘faint to very faint’ class quasi-persistent X-ray binaries - XMM1747 and SAX1806, which are going through the very long X-ray outbursts. We obtained observations of XMM1747 using the PANIC instrument on Magellan telescope in 2008 while the observations of SAX1806 were obtained in 2011 using the WHIRC instrument on 3.5-meter WIYN telescope.

We identified two NIR stars consistent with the *Chandra* error circle of our source XMM1747, marked as C1 and C2 in Figure 1. We compared our observations with the UKIRT observations of the source obtained in 2006 which were also taken during the current outburst of the source and showed that the star C1 was detected with the similar magnitudes during the two epochs while the star C2 showed significant variations in all the bands. Our color-color diagram analysis showed that star C2 is suffering a bit more extinction than most of the stars in the field. Assuming that all the NIR emission is from the companion star, the  $K$  band flux of star C1 suggest a high mass star of spectral type O or B to be the possible counterparts if it lies close to a distance of 8 kpc. Similarly, the  $K$  band flux of star C2 from the Magellan observations suggest a high mass star e.g., B type while the UKIRT observations suggest a A-type star for given magnitudes.

The LMXBs generally show a large variations in the OIR fluxes during their X-ray outburst (reference) and none



**Figure 4.** Left :  $K_s$  band image of the SAX J1806.5–2215 taken using the WHIRC instrument on the 3.5-meter WIYN telescope. Right :  $K$  band image of SAX J1806.5–2215 from the UKIDSS Galactic plane survey.

of the sources which showed type-I X-ray bursts have ever been associated with a high mass companion. Both these arguments suggest that star C1 is not the real counterpart. However the power-law fit with an index of -2.5 suggests that it could be a disk dominated star. We note that the wavelength range for a power-law fit is small and considering that we have large uncertainty on the optical extinction, the power-law index could be misleading. Also the wind accretion from high-mass counterpart cannot be denied, and if true, XMM1747 would be the first X-ray burster from a high mass X-ray binary. From all these arguments, star C1 is likely not the real counterpart.

On the other hand, star C2 showed a significant variations during the two epochs and if the Galactic extinction as measured by Dickey and Lockman (1990) represent the true extinction for this source, in which case it would be a A-type star, then it might be possible that the NIR source is associated with XMM1747.

However the fact that XMM1747 is lying in a very crowded field in the NIR bands, which is also suggested by detection of two stars in the *Chandra* error circle of the source show that the chance coincidence of detection of a foreground star is very high. Also due to the high extinction towards the source, we cannot deny that the real counterpart might not have been detected. From the Magellan observations, we measured the limiting magnitude of 20.0 mag in the  $K$  band. Hence if the real counterpart was indeed not detected during our observations, then the observed  $K$  band magnitude of the counterpart would be 20.0 mag or fainter, which indicate a star of spectral type later than K -type, which is not unexpected for LMXBs.

For SAX1806, we detected a NIR star of magnitude 17.21 mag in  $K$  band during the X-ray outburst, consistent with its *Chandra* error circle. This star was not detected during the UKIRT observations which were taken during the quiescence state of the source and suggest a magnitude of 18.2 mag or fainter in  $K$  band. The increase in brightness by one magnitude during the X-ray outburst as compared to the quiescence suggest the detected NIR star is the likely

counterpart of SAX1806. If true, the real magnitude of the NIR counterpart would be fainter than 18.2 mag and hence suggest a companion star close to a star of spectral type F or later.

The OIR spectrum of LMXBs during outbursts show a number of double profile emission lines of H and He (Kaur et al. 2012a), indicating the presence of accretion disk. However during the quiescence state, the OIR spectrum would be dominated by the spectral signatures of the companion star. The NIR spectroscopic observations during the outburst or quiescence state can unveil if the suggested stars are the real counterparts.

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